Spectral Analysis in Airborne Electromagnetics

EM 1.1

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Abstract

Spectral analysis of profiles across isolated conductors using the INPUT® airborne electromagnetic (EM) system can be used in the interpretation of data acquired over thin conductive plates in terms of the depth and size of the plate. Spectral analysis works because the currents in a thin conductive plate are confined to flow in the plane of the plate and the induced dipole moment is always perpendicular to the plate. Hence the position of the transmitter is not critical except in determining the amplitude of the induced currents. The moving receiver measures the anomalous fields associated with a stationary target. For a given measurement time, the depth of vertical targets can be easily determined from the slope of the amplitude spectrum; but the depth of horizontal targets is more difficult to define. In this case, however, the size of the target can be determined from the complex shape of the spectrum. The method can also be used in the interpretation of thin conductors beneath conductive overburden.

Introduction

Spectral analysis is a tool long used in gravity and magnetics for separating regional and local anomalous features. Mainly it involves spatial filtering of two-dimensional maps but also includes filtering of data to eliminate noise and enhance the relative conductor response (Fraser et al., 1966). Botha et al. (1986) suggested that wavenumber-domain filtering of the EM response over a conductive host rock containing a conductive target was useful in removing the host rock response for a TURAM-type EM prospecting system. The above examples assume a stationary transmitter for the measurement in question. This situation differs radically from the airborne EM case where the transmitter and receiver are fixed relative to each other, but move with respect to the target. Here, data is collected as a function of profile position and time, and each profile in time can be transformed from the space-domain to the wavenumber-domain by using a Fourier transform. We have chosen to do our spectral analysis interpretation using the geometrical and time parameters of the INPUT airborne EM system. The PLATE program (Dyck et al., 1980) was used to numerically model the response of thin conductive plates in free-space.

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Theory and approximations

One of the standard assumptions in the use of spectral analysis for gravity and magnetics interpretation is that the measured field results from a stationary transmitter. This is obviously not the case in airborne EM where the transmitter and receiver move in tandem across the conductor. However, for a confined thin conductor in free-space, the receiver measures the anomalous fields produced by currents flowing in the conductor. For a thin conductor, these currents are confined to flow in the plane of the conductor and have an induced dipole moment perpendicular to the conductor. The current distribution does not change with transmitter position, only the amplitude of the induced currents changes. Hence the receiver measures the anomalous fields from a stationary target with a relatively unchanging current distribution as long as the geometrical relationship between the transmitter and receiver allows for a fairly uniform energizing field to induce currents in the target.

Each component of the measured anomalous field satisfies Laplace's equation. Analysis of these field components in the wavenumber-domain should then show an exponential relationship with respect to depth. This can be most easily demonstrated for a large thin vertical conductor where the anomalous current can be represented by an infinite line source near the top of the conductor. Since we are using the INPUT airborne EM system, we will be concerned with the horizontal field arising from such a source. The horizontal magnetic field from a line source is

$$H_x(x,z)=\frac{I}{2\pi}\cdot\frac{z}{x^2+z^2}. \qquad (1)$$

Transforming the x spatial variable to the wavenumber-domain yields:

$$H_x(k_x,z)=\frac{\mathrm{I}}{2\sqrt{2\pi}}e^{-z\left|k_x\right|}. \qquad (2)$$

Thus if one were to collect x-component data over an infinite line source and transform the data into the wavenumber-domain, the depth of the line source could be interpreted from the slope of the amplitude spectrum of the wavenumber-domain data.

It can be demonstrated that the current patterns decay toward the center of the conductor with time (Bartel and Hohmann, 1985). Hence, the depth and size estimates at early times may not be the same as at late times, but their variation will reflect the true nature of the target. Such changes will be systematic and somewhat predictable in the scope of making an interpretation. The speed at which this current collapse occurs depends on the conductance and size of the target.

Methodology

The numerical results used in the spectral analysis interpretation study were obtained by using program PLATE (Dyck et al., 1980). It computes the response of a thin conductive plate in free-space. Specifically, we used a vertical dipole transmitter and horizontal dipole receiver trailing the airplane at an angle of 35° and separated from it by a horizontal distance of 96. m. The transmitter flying height above the ground surface was 120 m. The standard INPUT system parameters (Lazenby, 1973) were modified by an increase in the waveform period to 30 milliseconds (ms) and by the measurement of the response out to 10 ms after primary field extinction. The pulse length of the half-sine transmitter pulse was set at 1.8 ms.

Since computational considerations necessitate a limitation on the number of profile positions that can be computed with one pass through the PLATE program, we found it advantageous to use other techniques to insure a smooth function in the wavenumber-domain. Normally, a maximum of 51 profile positions may be computed with each run of the PLATE program. These profile points are evenly spaced and positioned such that the conductor is centered in the computed profile. The response at these 51 profile points is then centered in a 256 point vector, otherwise containing zeros, to represent a longer profile. To insure a smooth transition from the first or last computed response and the zeros padded on both ends, a cosine taper was used to smooth the response beyond the ends of the numerically computed data. This operation resembles the use of a Tukey window on the data. A numerical Fourier transform was then performed on this 256 point vector in order to obtain the amplitude and phase spectra in the wavenumber-domain.

Results

Results of the transform in the wavenumber-domain are plotted as amplitude versus frequency/data interval on a semi-log plot. From the frequency/data interval, one can obtain the actual wavenumber by knowing the data interval. It was found that the actual data interval was not critical as long as the response was adequately modeled, except that the actual wavenumbers sampled does change, since only wavenumbers up to $0.5\times(1/\text{data interval})$ can be sampled.

Figure 1 shows the amplitude spectrum for a vertical target 120 m below the transmitter. The wavenumber response is plotted as different times at 0.1, 0.3, 1.0, 3.0, and 10. ms after transmitter current shut-off. The overall shape of the wavenumber response does not change with time. The slope of the fall-off increases slightly at late times because the representative current filament at the top of the conductor is migrating toward the center. The numerical value of the slope can be used to determine the depth of the target, especially at early times as shown in Figure 2. The best-fit line in Figure 2 represents a fit to the early-time amplitude slopes and the error bars show the extent of the slope change with time. The x-intercept of the best-fit line in Figure 2 is approximately one-half the receiver height above the conductor.

Figure 3 shows the amplitude spectrum for a horizontal conductor that is 120 m below the transmitter. While there is evidence of the same amplitude fall-off relationship demonstrated in Figure 1 for vertical targets, the character of the response is quite different. Analyzing the positions of the zeros of the amplitude response at early times, we found that they correspond to the size of the thin plate. The first zero occurs at a wavelength of approximately W (where $W=$ plate width and strike length), the next at $W/2$, the next at $W/3$, and so on. At later times these zeros migrate to higher wavenumbers (smaller wavelengths), again representing a collapse of the induced currents toward the center of the thin plate. What these zeros appear to represent is the size of the equivalent current loop generated in the plate.

Discussion

Spectral analysis is a new technique for interpreting EM profiles, in particular those of the INPUT airborne EM system. Its main application appears to be in interpreting profiles over thin conductors where the induced currents are constrained to flow in one plane. Simple models representing the current in the conductor can be used to generally explain the features seen on the amplitude spectra of thin conductive plates. This interpretation method will be of use in estimating the depth and size of isolated conductors.

This method should also be applicable for interpreting thin conductive targets beneath conductive overburden. At late times, the target signal is not affected by the presence of the overburden whose response is merely additive (Bartel and Becker, 1987). Since the overburden response then only provides a DC component, it should not affect the Fourier transform of the conductor signal. Because it appears to discriminate between horizontal and vertical conductors, this technique should be useful for differentiating between surficial and bedrock conductors.

Acknowledgements

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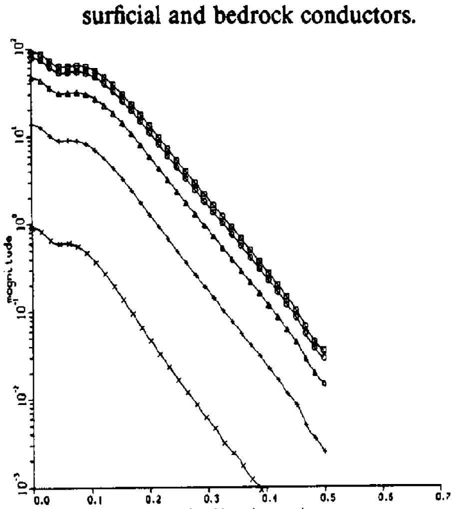

FIG. 1. Amplitude spectrum of vertical target. Depth below transmitter = 120 m, conductance = 100 S, width = strike length = 300 m, data interval = 19.1 m. Times of measurement: squares = 0.1 ms, circles = 0.3 ms, triangles = 1.0 ms, plus sign = 3.0 ms, and x = 10 ms.

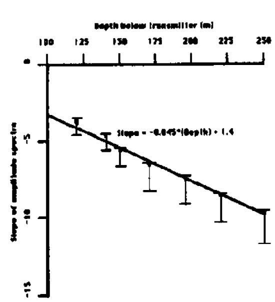

FIG. 2. Depth below transmitter determination from slope of amplitude spectrum; circle = early time slope estimates and error bars show extent of late time change.

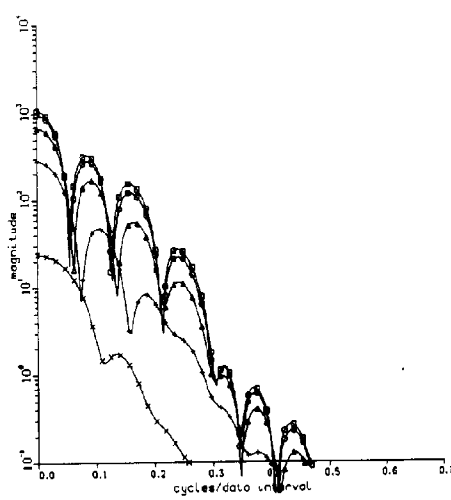

FIG. 3. Amplitude spectrum of a horizontal target. Depth below transmitter = 120 m, conductance = 100 S, width = strike length = 300 m, data interval = 19.1 m. Legend for times of measurement same as for Figure 1.